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Public private partnerships and emerging technologies: A look at nanomedicine for diseases of poverty

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ABSTRACT

Emerging technologies, like nanotechnology, are often hailed as transformative technologies that will not only help the rich, but be used to decrease poverty and inequality. In order to overcome many of the challenges associated with developing products for poor communities, especially medicines for the poor, institutions setup organizations called public private partnership (PPPs). This study examines whether PPPs are developing nanotechnology to make medicines for diseases of poverty (DoP). PPPs are the main actors researching medicines for DoP and if they are not involved with nanotechnology research, then it is unlikely that nanomedicines for DoP will be developed. Through interviews and website content analysis, this study finds that there are only a few PPPs doing nanomedicine research. Many of the PPPs are worried that the technology is too expensive and it will take too long to bring nanomedicines to the market. To increase the likelihood that emerging technologies, like nanotechnology, will be used to mitigate poverty, policy makers can do several things like change the patent laws to encourage innovation on technologies for the poor, increase research funding in areas that address development, and move pro-poor technologies quickly through the regulation process.

1. Introduction

Many of the world's deadly diseases have been eradicated through a variety of technologies and social improvements. Some diseases were addressed by better medications, treatment regimens and vaccines, while other diseases were eradicated due to improved cleanliness standards that prevented pestilence from spreading. Despite the improvements in overall health, the advancements are not evenly distributed. Many medical discoveries only target diseases of the very rich and other medicines are too expensive for impoverished communities to purchase. At one point scholars estimated that there was a "10–90 gap" in health research because they found that less than 10% of healthcare research and development (R&D) was on diseases that affect 90% of the world's population (Murray et al., 2012). Today the gap is not 10–90, but there are many diseases that predominantly affect the poor that receive little R&D funding (Moran, 2005).

Most scholars identify about 40 disease of poverty (DoP) (Moran et al., 2010; World Health Organization, 2010) and the healthcare literature attributes a portion of global health inequality to the lack of a profitable market associated with DoP medicines (Chataway et al., 2010; Moran et al., 2010; Widdus, 2001). Scholars reason that biotechnology and pharmaceutical companies will not develop new medicines to target DoP if they cannot recoup their R&D expenses, and as a result, there is less R&D and medicines for DoP.

To overcome the small market for DoP treatments, scholars believe that it is necessary to develop special organizational structures called public-private partnerships (PPPs) (Chataway et al., 2010; Moran et al., 2010; Widdus, 2001). PPPs can improve the DoP medicine market by connecting pharmaceutical suppliers with customers and lowering the barriers to entry so pharmaceutical companies can develop and sell medicines for DoP. PPPs also provide research funds, link companies to government health organizations, participate in manufacturing and assist with distribution and marketing (Glennerster et al., 2006; Widdus, 2001). These efforts can spur drug development on DoP, make the current medicines more accessible, and lead to inclusive innovations.

One new health technology that some scientists believe will revolutionized healthcare is nanotechnology. Scientists hope medical applications of nanotechnology (nanomedicine) will lead to things like targeted drug delivery systems, nearly instantaneous disease detection sensors and stronger, yet flexible, prosthetics (Invernizzi,

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2006). However, nanotechnology, and other emerging technologies, only have viable futures if there is a market for them (Cozzens et al., 2010). If there is no market for a technology, then companies do not have an incentive to develop and sell them. Yet, the market for DoP medicines is unclear because companies are unlikely to recoup their research expenses and make a profit on medicines for diseases that affect the poor (Kremer, 2002). Therefore, there is an interesting intersection between PPPs, nanomedicine and inclusive innovation. According to current academic theory, emerging technologies, which could have an impact on the poor, will only be used to address DoP if a market exists. PPPs can help build and maintain a market, and as a consequence, entrepreneurs and scientists will use emerging technologies, like nanomedicine, for inclusive development (Glennerster et al., 2006).

This study investigates the role of PPPs for DoP medicine development and whether they are researching nanomedicine. It adds to the literature on PPPs by considering the extent that this organizational structure can develop emerging technologies for inclusive development. How do PPPs decide the types of projects to pursue? Do PPPs think nanomedicine is a viable field? Is there evidence of a relationship between PPPs and emerging technologies? I use a mixture of primary and secondary sources to understand the motivations of PPPs, their research priorities, and importantly, whether PPPs can overcome market deficiencies to provide emerging technologies for inclusive development. This paper begins by giving an overview of the relevant literature and the research methods. Then, I discuss the research findings and policy implications.

2. Literature review

2.1. Public private partnerships

PPPs are not new institutions; rather, governments have partnered with private organizations to provide public services for hundreds of years. For example, the Dutch East India Company was a partnership between the Dutch government and industry to encourage world-wide trade and during World War II, governments heavily relied on the private industry to provide supplies and services for the war movement (Wettenhall, 2005). Despite the prevalence of government and non-government partnerships, the term public-private partnership was first used about 40 years ago (Bovaird, 2004) and since then, it has grown in prominence. PPPs span sectors and have a variety of functions like policy design, policy evaluation and monitoring, implementation, capacity building, activism and resource mobilization (Bovaird, 2004; Brinkerhoff and Brinkerhoff, 2011).

One heavily cited definition of PPPs is "working arrangements based on a mutual commitment (over and above that implied in any contract) between a public sector organization with any organization outside of the public sector" (Bovaird, 2004). This definition is broad and it allows PPPs to have assorted organizational structures ranging from partnerships between national government agencies and companies to partnerships between local government departments and community group.

These type of organizations form for a variety of reasons. First, the complexity and interconnectivity of problems prohibit a single organization from accomplishing their goals, so in order to succeed, organizations must partner together (McQuaid, 2000; Van Ham and Koppenjan, 2001). The need to partner due to increased complexity is especially relevant for organizations working with highly scientific emerging technologies. These technologies are at the forefront of knowledge, and a variety of sectors must share knowledge in order to develop them (Cozzens et al., 2010).

A second reason that organizations form PPPs is that a group of organizations can better overcome market deficiencies than a single actor (McQuaid, 2000; Van Ham and Koppenjan, 2001). For example, some innovations have high technical risk that prevent them from being economically attractive, while other innovations have low monetary return. PPPs can circumvent these barriers by spreading the risk of failure over multiple parties and projects (Greve, 2006).

Partnerships also improve the economies of scale of R&D and pool talents across different sectors (Bovaird, 2004). Most health PPPs have expert scientific boards from industry, academia and non-profit organizations that assist managers to choose research portfolios that align with the goals of the organization. The boards' consider the cost and feasibly of projects to decide whether to pursue them (Munoz et al., 2015). In contrast, independent organizations may not have the personnel and financial resources to manage, evaluate, and implement multiple highly technical projects (Moran et al., 2010).

However, not all scholars think that PPPs are beneficial for inclusive development. Miraftab describes PPPs as Trojan Horses that hide unequal power relationships and lead to community partners being marginalized by the dominant partner. Asymmetric power relationships are especially prone to occur with low-income communities because poor constituents have fewer resources to make their voices heard (Miraftab, 2004). Rather than thinking of PPPs as a panacea to problems, Miraftab suggests that PPPs focus on improving social, economic and cultural conditions (Miraftab, 2004). Simply forming a PPP does not guarantee equitable outcomes.

Since there are so many types PPPs, this paper focuses on a subset of PPP's called product development partnerships (PDPs). Chataway et al. defines PDPs as a "technology push initiative aimed at providing new science and technology based products for neglected diseases" (Chataway et al., 2009). The majority of health PPPs/PDPs began around 1999 (Munoz et al., 2015; The Economist, 2013), and at that time, several factors converged to create a public buzz to address DoP. In 1999, there was substantial public outrage directed at pharmaceutical companies because they refused to provide low-cost HIV medicines to victims in poor countries. In response to the negative publicity, many of the big pharmaceutical companies began researching medicines for DoP and giving their technology to researchers working on these diseases (The Economist, 2013). Moreover, in 2000 the United Nations launched the Millennium Development Goals (MDGs) and increased the visibility of DoP. This made the world community more responsive to the needs of the poor and it put public pressure on countries to find solutions for these issues. Similarly, celebrity activists, like Bono and Angelina Jolie, and large non-profit organizations, like the Bill and Melinda Gates Foundation, highlighted the importance of global health and many of these activists viewed PPPs as a the vehicle to leverage the advantages of the private sector to address poverty issues (Cohen, 2006).

PPPs are now the principal organizations developing medicines for DoP (Grace, 2010; Moran et al., 2010; Munoz et al., 2015). Moran estimates that in 2004 75% of R&D projects for neglected diseases were conducted by PPPs (Moran, 2005) and that 14 PPPs spent $262 million on neglected disease R&D in 2007 (Moran et al., 2010). In addition, by 2010 PPPs brought 10 new health products to market and it had another 122 treatments in the pipeline (Grace, 2010).

Health PPPs are described as " 'system integrators' that leverage the resources and capabilities of a network of a public, philanthropic and private sector partners" (Munoz et al., 2015). Chataway et al. find that prominent PPPs are knowledge brokers and integrators that drive innovation, stimulate R&D and negotiate among other organizations in the biomedical research innovation system (Chataway et al., 2007). However, previous studies do not investigate whether PPPs actually develop emerging technologies for poverty alleviation and there is some doubt that PPPs can really

Table 1
List of PPP/PDP studied.

List of formal PPPs	
Aeras	International AIDS Vaccine Initiative (IAVI)
Buruli Vac Consortium	International Partnership for Microbicides (IPM)
Consortium for Parasitic Drug Delivery	International Vaccine Institute (IVI)
Drugs for Neglected Diseases initiative (DNDi)	Malaria Vaccine Initiative (MVI)
European Vaccine Initiative (EVI)	Medicines for Malaria Venture (MMV)
European and Developing Countries Clinical Trials Partnership	Meningitis Vaccine Project (MVP)
European Solutions Enterprise on Neglected Diseases	Novartis Institute for Tropical Diseases
Foundation for Innovative New Diagnostics (FIND)	One World Health (OWH)
Global Solutions for Infectious Diseases	Program for Appropriate Technology in Health (PATH)
Global Alliance for TB Drug Development (TB Alliance)	Sabin Vaccine Institute
Global Alliance for Vaccines and Immunisation	The Vizier Project
Global HIV Vaccine Enterprise	TI Pharma
Infectious Disease Research Institute (IDRI)	TuBerculosis Vaccine Initiative (TBVI)
Innovative Vector Control Consortium (IVCC)	WHO: Special Programme for Research and Training in Tropical Diseases (WHO/TDR)

develop emerging technologies cheaper than traditional pharmaceutical companies (Grace, 2010).

2.2. Emerging technology and nanotechnology

There is no universal definition of emerging technologies; however, they can be described as technologies that have fast and recent growth; transition to something new; have prominent impact; and based on scientific innovations and breakthroughs (Cozzens et al., 2010; Rotolo et al., 2015). Emerging technologies are important for economic growth because they overthrow status quo technologies with time saving devices, create new industrial opportunities and revive dying economies (Avila-Robinson and Miyazaki, 2011; Day and Schoemaker, 2000). Because new and emerging technologies are so central to economic growth national governments, industries, and universities invest a lot of resources in R&D for emerging technologies.

One emerging technology that has received a great deal of attention over the past decade is nanotechnology, which "is the understanding and control of matter at dimensions between approximately 1 and 100 nanometers" (National Science and Technology Council, 2011). At the nanoscale matter has different properties, like conductivity or reactivity, and these unique properties make it possible to do novel research and create new products. Some of the most promising nanotechnology products are related to energy systems, metal alloys, healthcare and computer chips.

The nanotechnology revolution began around 2000 with the establishment of the USA National Nanotechnology Initiative (NNI). It initially received $475 million and over the past 15 years, its funding has steadily grown (United States National Nanotechnology Initiative, 2015). Other countries made similarly large investments in nanotechnology and by 2004 about 62 countries, of which 12 were lower income countries, had some type of nanotechnology initiative (Maclurcan, 2010).

A large subset of the nanotechnology field is nanomedicine. The idea of nanomedicine can be traced back to Richard Feynman, who is often attributed as the father of nanotechnology (Freitas, 2005). In his famous speech, there's "Plenty of Room at the Bottom", Feynman describes a future where little robots would be surgeons inside the body and doctors could permanently implant devices to help organs function (Feynman, 1959). Today, scientists are trying their best to realize Feynman's dream, and they have developed things like diagnostic tools, drug delivery systems and implants/prosthetics (Freitas, 2005; Invernizzi, 2006). Nanomedicine is still in its infancy, but in 2011, nanomedicine was a $50.1 billion market with expectations that it would grow to a $97 billion market by 2016 (Evers, 2012).

Most nanomedicine R&D occurs in the USA and Europe on diseases like cancer or diabetes (Woodson, 2012). However, nanomedicine is not only relevant for non-communicable diseases. Scientists could use the technology to development treatments for infectious diseases, like malaria and tuberculosis, and other diseases that predominantly impact the poor (Sosnik and Amiji, 2010). Unfortunately, much of the inequality in health R&D persists in nanomedicine R&D (Woodson, 2012). So, even though nanomedicine has received significant attention in the health innovation system, DoP nanomedicines are still are a small part of the research agenda (Sosnik and Amiji, 2010; Woodson, 2012).

3. Methods

This study uses two main sources of data, PPP websites and semi structured interviews, to examine PPP nanomedicine research. By using both the websites and interviews, I capture more information that can be used to triangulate the results to make stronger conclusions. I started the analysis by examining the websites of the various PPPs. These websites are very detailed, and most PPPs websites discuss their funding sources, research portfolios and the reasons their organization is best suited for DoP research. Also, the websites usually have internal search engines that allowed me to search explicitly for information related to nanotechnology and poverty alleviation. Once the data was collected and downloaded, the relevant text from each website was uploaded into Nvivo (a qualitative data management software) to be coded and analyzed. The list of PPPs studied in this project, see Table 1, was derived from other studies on health PPPs (Grace, 2010; Moran et al., 2010).

Next, I interviewed scientists and PPP managers. I chose these actors because managers have the most information about the mission of the PPP and the way the organization sets research priorities. Scientists, on the other hand, understand technical details about research portfolios and the potential of nanotechnology. The interviews took place from June 2013 to July 2014 and were 30 min to one hour long. Table 2 lists the interview questions. After conducting an interview, I transcribed and uploaded it into Nvivo for analysis. I conducted a total of 14 interviews. Eleven of the interviews were with managers and scientists at 10 different PPPs. Three of the interviews were with university scientists who partner with PPPs. Therefore, out of the 28 PPPs I considered in this study, I interviewed someone from 10 of the PPPs and collected website information for 24 of them. Four of the PPPs were defunct or had merged with another organization at the time of the study.

Once I collected the data, I used web-based content analysis methods to analyze the data and extract useful information (Herring, 2010; McMillan, 2000; Weare and Lin, 2000). The codes used to sort the data are found in Table 3. The initial codes were developed from the literature on PPPs, but additional codes were added as other topics became apparent.

Table 2
Interview questions.

Interview Questions	
Introduction/Background	What is your background? What do you do within your organization? Give a brief overview of your organization?
Research/Focus	What is your research? Who funds your research? How did you choose your research area? What are some successes you have had in your research? Who are your research partners? How long have you been working in this area? What types of project will you do in the future?
Nanomedicine	Are you doing any work in nanomedicine? Why (or why not) are you doing work in nanomedicine? Do you think nanomedicine is useful for DoP R&D?
PPP	Do you consider your organization a public private partnership? If so why? What is the structure of your PPP? Who funds the PPP? Where do PPPs fit within research and drug discovery? Are PPPs necessary to find medicines for DoP? How does your organization use patents, and publications? How does your PPP choose its research foci? Do you think PPPs are the new normal for drug development Do you collaborate/talk with other PPPs? All PPPs seemed to spring up at the same time. Do you have any clues why?
DoP	In your opinion what are the most problematic DoP? What research areas are necessary to reduce the burden of disease from DoP?

Table 3
Content analysis coding.

Codes	Code Explanation
Disease of poverty	Any mention of a disease of poverty
Diseases	Any mention to a non-DoP
Drug Delivery	Any mention to drug delivery systems
Funding	information on who funds the PPP or how much money they have
Future	any reference to the future (i.e. the future of the PPP or DoP research)
Governance	Information on the governance structure of the PPP
History	History/origins of the PPP start?
International	Any mention to countries working with PPP
Model	Explanation of the PPP model and why it is important
Nanotechnology	Any reference to nanotechnology
Partners	Who is the PPP working with?
Portfolio	Information on the research projects
Publishing/patenting	Information on publishing and patenting habits of organization or researcher.
Scientist	Any reference to a specific researcher
Sensors	Any reference to sensor technology
Skills	Mentioning a specific skill of scientists or the PPP

The websites and interviews provide rich data, but like all research methods, these techniques have limitations. One major disadvantage of the interviews is that I had a small sample size. It was difficult getting PPP managers and scientists to respond to my phone calls and emails. The non-response rate could bias my results and limit the conclusions that I can draw from the analysis. Also, the websites have a lot of information, but they only give the perspective of the PPPs. To mitigate this bias, I interviewed a few experts that do not work for PPPs in order to get their opinion about the organizations and DoP nanomedicines.

4. Results

4.1. Importance of PPPs

The first observed trend in the study is that PPPs are keen to communicate that they are different than pharmaceutical companies and their unique mission allows them to pursue technologies that traditional pharmaceutical companies would not consider. For example, Medicines for Malaria Ventures (MMV) devotes sections of their webpage to describing PPP and PDPs. They even feature video interviews and animations explaining the importance of PDPs (http://www.mmv.org/). They say that PDPs

> *"...act as a facilitator, bringing dedicated sources of funding and know-how to committed researchers so they can collaborate on the right projects to fulfill the objectives of the PDPs mission. The specific objectives of individual PDPs vary, but the basic mission is the same: to develop pharmaceutical products for use as a public good to address the health needs of vulnerable populations in the developing world."*

PPPs view themselves as changing the traditional model of pharmaceutical drug manufacturers in order to provide medicines for the poor and underserved populations. They employ terms like "uniquely positioned" or "bridges" to show their centrality for DoP R&D. PPPs highlight that the complexity of the healthcare system requires organizations to work together and PPPs are able to fill that gap. One manager explains that,

". . . if you go back 50 years ago you had one chemist and a doctor who would try a medicine out on patients. Now you have a whole range of skills from chemists to biologists to toxicologists (who make sure things are safe). It's become much more of a team effort."

This manager emphasizes the myriad of skills necessary for drug development and a single organizational entity cannot do everything. Different organizations have to work together because one actor cannot accomplish the goal.

Not only do PPPs view themselves as bridging a skill gap between sectors, but they think they bring together actors with distinct incentives. Industry and academia have differing reward systems and structures. Industry is concerned with generating a profit, while academics are more concerned with producing top research. As one manager says,

"Academic cultures and industrial cultures are by definition different. . . Which means the goal needs to be a concrete goal for the industry which is not the same for the academic environment who can have a lot of benefit from excellent publications but will never lead to a concrete drug that will be brought to the market."

This manager explains that the different cultures between pharmaceutical firms and academic institutions affect their research and partnerships. However, PPPs can bridge the two cultures and make it easier to work together.

A second factor that PPPs use to justify their competitive advantage to develop emerging technologies is that they believe they are the best organizations at picking technology for DoP medicines. PPPs maintain that academia and industry have incentives that lock them into certain research trajectories and prevent them from choosing a viable research path. PPPs, on the other hand, believe that they are better judges of successful research lines because they are more impartial.

"The venture capital industry is all about putting the right projects together and funding them for as long as they need and giving them all the money they need up to key decision points and then stopping. It's a very different funding model than say an academic crowd where you write a proposal and get money for five years. And at the end of five years you have to explain what you've did with it. So I think when you look at the big consortia [PPP] model, its better suited to the venture capital model. Let pay be based on rewards and stop if it's not working"

The PPPs manage and "prune" research portfolios in order to maximize the potential of the research. If a certain research path is a dead-end, PPPs feel that they can quickly end them.

Finally, PPPs repeatedly say that they fix the lack of commercial interest for DoP R&D. One PPP's website says that one of their main purposes is to address this market failure.

"*PDPs address the lack of commercial incentive to undertake R&D for vaccines, diagnostics, and drugs for neglected diseases of the developing world. They use public and philanthropic funds to engage the pharmaceutical industry and academic research institutions in undertaking R&D for diseases of the developing world that they would normally be unable or unwilling to pursue independently. . .*"

This PPP discusses how they use funds from several sources in order to bring together participants to pursue the same project. A manager at a PPP explains that partnerships lower the risk to companies. If an individual company tries to develop a novel drug treatment and it fails, then they could lose a lot of money. However, by partnering with a PPP, the company is less exposed to poor research portfolios because their R&D expenses are pooled with other investors. The manager explains that,

"In order for a company to make an investment in developing a technology and providing it. . .the technology has to make sense financially for them and PPP_B fills in the gap is by helping to de-risk the process"

4.2. Types of PPPs

Another finding that became apparent during this study is that there are different types of PPPs and the organizational structure influences whether they research emerging technologies. From the analysis, health PPPs can be divided into two broad groups: R&D PPPs; and advocacy, education and medicine pricing PPPs. Some of the larger PPPs perform all of these roles, but often the partnerships specialize in either R&D or the downstream aspects of the health innovation system. The R&D PPPs are especially interesting for this study because they were the only PPPs that were developing DoP nanomedicines. The advocacy, education, and pricing PPPs, on the other hand, implemented innovative supply chain or education programs to decrease health inequality.

The R&D PPPs can be further divided into in-house R&D lab and R&D managers. The in-house R&D PPPs function like academic research labs. These PPPs are awarded research grants from large foundations and government agencies to pursue a particular medicine for a disease. One key resource of in-house R&D PPPs is that they share administration resources in order to reduce costs. A manager of an in-house R&D PPP says that,

"We leverage the fact that we maximize the resources because we are imbedded in institutions that already have a lot of resources. For instance I don't have to worry about ethic reviews because we utilize the IRB of our institutions . . . therefore, the funding we receive is much better utilized because we don't have to recreate the bureaucratic and administrative system. . .. It's like having a biotechnology company embedded within an academic institution."

This manager believes that their close affiliation with a university helps the organization be more effective with their resources because they can utilize the university's research infrastructure.

The other type of R&D PPPs act as knowledge facilitators. Rather than doing all the research in-house, these PPPs contract the work to other scientists. A typical scenario for a knowledge facilitator is that they will find research grants and then redistribute the money to other research labs. For example a PPP manger says,

"Well for each project we have to write a proposal to a donor and get funding for a specific scope of work. . . And then depending on the role of PPP_X, it might be managing the project or grant out the money to the collaborators"

Another PPP mangers explains that

"PPP_A's R&D expenditure is generally not direct expenditure, but is in the form of grants and contracts with external parties who perform certain tasks at its request"

Both of these PPPs act as project managers and intermediary for grant agencies.

In the interviews I asked PPPs about their choice to outsource R&D projects instead of using in-house R&D labs. Most of the knowledge facilitator PPPs responded that outsourcing R&D saves money and allows them to better manage the projects. Another benefit is that outsourcing lets the PPP focus its attention on managing the research portfolio instead managing a lab. The in-house R&D PPPs were normally started as university spin-offs and they continued on particular R&D pathways. There was not a discernable relationship between the type of R&D PPP and whether they are developing nanomedicines. Both in-house R&D and R&D management PPPs conducted nanomedicine research. However, it is clear

that only PPPs that concentrate on R&D, as opposed to advocacy and pricing, will even consider pursing emerging technologies like nanomedicine.

4.3. Nanotechnology and PPPs

A key goal of this paper is to understand the role that PPPs play in advancing research on emerging technologies that could reduce poverty and inequality. Overall, the managers and scientists give a wide range of answers on the reasons they choose to study nanotechnology for DoP research. Several PPPs are actively engaged with nanotechnology and believe that it is a smart research path, while other partnerships think nanomedicine is not good for DoP medicines. The sample can be loosely divided into pro-nanotechnology and anti-nanotechnology organizations. The pro-nanotechnology organizations are working on novel drug delivery systems, like encapsulating medicine inside nanoparticles for TB or HIV/AIDs medicines, and creating special bandages that slowly release medicine.

Some of the pro-nanomedicine scientists are very positive about the potential of the technology. One optimistic scientists says that

> *"Nanoparticles are not only [good] for delivery drug, but you can imagine many things. There is no limit to how you imagine nanoparticles. . . [there] are so many applications of nanotechnology because you can make smart nanoparticles· · ·You can track down your drug, do diagnostics. . . you can do many things"*

In general, pro-nanotechnology PPPs believe that the current treatments are not ideal and that nanotechnology can be helpful for DoP medicines (Sosnik and Amiji, 2010). New nanomedicines could shorten treatment times, have fewer side effects and simplify the treatment regimen. This is especially important in poor regions.

Another pro-nanomedicine interviewee thinks nanotechnology had potential, but the initial optimism of the technology has waned. Her PPP partners with nanotechnology scientists for drug delivery systems, but nanotechnology is a small part of her R&D portfolio. The manager says that,

> *"I think with every new technology there's always a spike of initial excitement and enthusiasm . . .. And then with more work and knowledge it becomes more tempered. People realize nano may be good for certain things but it's not going to make sense for other things"*

This PPP manager believes that nanotechnology could be useful in developing medicines for DoP, but nanomedicine will be one piece of a multi-faceted approach.

The anti-nanomedicine interviewees think the technology would be useful for other medical areas, but not for DoP. Their main criticism focuses on the cost and regulatory constraints of the technology. They worry that nanomedicines will be too expensive to manufacture for drugs that require a very low price point. A manager at an HIV PPP says that

> *"We have to be pennies on the dollar for what our products are and governments to buy them and have them a part of their public health programs. Any technology that requires sophisticated manufacturing or high cost manufacturing is. . . though probably viable from a medical perspective, not viable from a cost perspective"*

This manager is not pursuing nanomedicine for HIV because she believes that the high costs of fabricating nanoparticles and getting them regulated would be too expensive for low cost HIV/AIDS medicine. Interestingly, individuals and managers working on DoP advocacy and price controls were less likely to think nanomedicine is useful for DoP.

Finally, I asked the pro-nanotechnology PPPs about the regulatory challenges posed by nanotechnology. Most of them responded that they are excited about the potential of nanomedicine for DoP, despite the challenges. One PPP manager said

> *But hey if someone doesn't start, then the data is never compiled. So even though we don't know if any of these things in our hands will become licensed, but we're evaluating them because we need to ensure that we have different alternatives."*

This manager sees the value of having a variety of medicines. She is excited about the potential of nanomedicine R&D despite the challenges.

4.4. Funding

An additional aspect that impacts the ability of PPPs to do DoP nanomedicine research is that the organizations must get funding to do the research. The PPPs in this study receive their funding from a mixture of government and private sector funds. However, the most prominent funders of PPPs are large foundations like the Bill and Melinda Gates Foundation (BMGF). Almost all the PPPs in this study have funding from the BMGF and in most instances the foundation provided the initial seed funding for the PPP. Similarly, other studies find that the BMGF dominates PPP funding. Moran et al. estimate that the BMGF provided about 50% of formal PPP funding in 2007 (Moran et al., 2010). Other than the BMGF, PPPs received funding from large donors like the USA National Institutes of Health (NIH), the Rockefeller Foundation, the US Agency for International Development (USAID), and western European countries like the UK, Germany, and Denmark. These organization invest a lot in R&D, but if they are not interested in pursuing nanotechnology, or other emerging technologies, then it is very difficult for PPPs to pursue these lines of research.

PPPs have a different relationship with corporate funding. Some PPPs receive major support from big pharmaceutical companies (big pharma), like Merck or Johnson & Johnson, while others tend to stay away from big pharma. One PPP says that big pharma is not interested in their organization because

> *"There is not a lot of commercial interest in the vaccines that we have in our portfolio versus something like malaria that may have multiuse"*

This PPP manager expresses that big pharma is not interested in their R&D because the corporate partner does not think it can profit from the R&D on obscure DoP.

A common complaint by the PPP managers is that there is a lack of overall funding for R&D and it is difficult to fund the basic operations of their organizations. During the recession in the late 2000s, all the donors, including large government agencies, slowed their outlays because they did not have extra money to fund non-profit activities. One scientists says that

> *"It seems to me that it's getting harder to do the work because of the funding environment. It's probably getting harder for everyone to work"*

Getting money for research on DoP is especially difficult. The same scientist goes on to say that finding research money for DoP R&D is

> ". . .a struggle because you look around and there are cancer grants from the university and things such as that and it's harder to find opportunities other than the NIH to keep your [DoP] research going"

Without sufficient research donations it is impossible for PPPs to pursue R&D for inclusive development.

As a consequence, several PPPs mention that they are targeting new sources of funding. One PPP in this study receives funding from the Fundación Carlos Slim, a foundation that has not traditionally supported biomedicine research, and the PPP is targeting high net worth individuals to support specific projects. Another funding diversification strategy that was mentioned is that PPPs are seeking out foundations that will provide matching funds for their current fundraising campaigns. The manager reasons that donors will be more likely to give if they are ensured that the money will be matched by another donor and the matching donor may feel more confident in their gift if other organizations vetted and support the project. A third money saving strategy for PPPs is that they use another organizations' lab and equipment instead of outfitting their own facilities. In this strategy, money may not exchange hands, but PPPs can receive a lot of benefits. One PPP manager explains that

"...the NIH will give us money, where we don't directly get the money, but we'll say we need to have this tested and they'll do it without charging us and without giving us money."

This type of in-kind work is a creative way to fund DoP research. The last strategy that was mentioned by PPPs is that they negotiate free supplies, compounds and formulas from pharmaceutical companies. Again, this saves PPPs money and lets them focus their resources on other aspects of their organization.

Finally, a major challenge expressed by PPPs is that donor organizations often put strict restrictions on the activities that they can do with the research money. For example, the donor may require that funds only be spent on a particular HIV project and prohibit transferring it to another experiment. In addition, many donors have very onerous reporting requirements. A PPP director says that,

"So reporting back to donors is extremely time consuming. Each donor is very specific about what their money can be spent on and we have to report back. That's an incredibly involved effort"

To comply with all the requirements, PPPs must hire full time staff members to handle the grant logistics. For smaller PPPs this is a big burden.

Therefore, given all the funding and reporting challenges facing PPP, they may not be able to research on emerging technologies simply because they do not have enough money to do this type of work.

4.5. Patents and publications

Another insight that is not discussed in other research on PPPs is that these organizations actively publish their findings. On their websites PPPs often cite their high publication rates as measures of success. One PPP report highlights that one of their main accomplishments in 2012 was publishing over 25 peer-reviewed journal articles that year.

PPPs publish for a variety of reasons. First, PPPs want to disseminate their information. A manager at a large PPP says that

"Publishing and disseminating information is a key part of what we do. We have principals of global access that we work with. Global access means that the technology we work on should be accessible as well as the information that we generate should be accessible. So we typically strive to publish our work as much as possible and build that into our agreements with our partners."

This manager expresses that sharing information is a key part of her organization's strategy and that publishing is a major part of that effort. Their dissemination strategy makes it easier for researchers in developing countries to access the results and use the finding in their own research. This helps nanotechnology become more accessible to less affluent nations.

Patenting is more complicated for PPPs than publishing. Each PPP approaches patenting slightly differently and PPPs have non-disclosure agreements that prevent them from sharing details about their IP and licensing arrangements (Munoz et al., 2015). However, a major theme expressed by the PPPs is that they use patents to protect themselves. Several PPPs worry that other organizations could prevent them from working on projects or steal their IP if they do not proactively patent their technology. One manager said,

"We approach the patenting aspect mostly to protect not because we foresee having some royalties generated. We protect mostly so that we can make sure no one interferes with us advancing this program"

Another way PPPs ensure that they have the necessary access to intellectual property (IP) is that they partner with biomedical companies on projects. In these partnerships, PPPs and pharmaceutical companies will develop special agreements that allow non-profit organizations to develop medicines for DoP without paying licensing fees. The pharmaceutical company retains the rights to use the technology in wealthy nations, but the PPP can use the technology for humanitarian purposes. One PPP website explains that

"Industry partners assign all rights to PPP_F for royalty-free use of their technology in the public and private non-profit sectors in high endemic countries, while the industry partner retains distribution rights for developed countries and the private sector in developing countries. This enables the partner to recover R&D costs and to create the returns needed to develop new technologies."

PPP_F explains that having different patent protection for different markets has allowed it to work with more companies.

"Our IP model has been successfully validated with industry partners and has contributed to an important and increasing number of contracts signed with large and small-sized companies."

PPPs learned to navigate patent hurdles in order to protect themselves and develop new technologies. These tactics are very helpful for PPPs to fully develop emerging technologies for inclusive development.

5. Conclusions/policy implications

From the interviews and website content analysis, I can draw two major conclusions about PPPs and their ability to conduct research and commercialize emerging technologies for inclusive development. First, the analysis confirms that health PPPs are central to the health innovation system for DoP research because they act as knowledge facilitators, utilize resources across sectors and wisely prune research portfolios to prioritize the most promising technologies. The advantages of PPPs allow them to overcome some of the barriers that dissuade the private sector from developing medicines for these diseases. Second, I conclude that the unique advantages of PPPs help them explore nanomedicines for DoP but PPPs cannot overcome all the barriers of developing nanomedicines, and other emerging technologies, for consumers in developing countries. Even if PPPs solve the technical challenges associated with developing inclusive emerging technologies, there are still obstacles with funding, regulations, and patents that can derail technology development and diffusion for marginalized groups. Given these conclusions, what type kind of policies could encourage PPPs to conduct R&D on emerging technologies for inclusive development?

One solution to encourage R&D for inclusive innovations, like nanotechnology, is that government regulators could offer fast track approval processes for technologies that help impoverished

communities in order to ensure that the technology reaches the market quickly. Fast-track approval gives PPPs more certainty that their novel products will not languish behind walls of regulations. These types of policies might seems easy to implement, but they face many ethical hurdles because regulators cannot authorize substandard products for low-income communities. However, if scientists robustly test the medicines, then they can ensure the products come to market quickly and safely. For example, the FDA could augment the "animal rule" so that more vaccines and medicines for DoP can apply for this exemption.

In addition, policymakers can to adopt special incentives and funding programs to encourage pro-poor research. One study finds that poverty related diseases cause 13.8% of global disease burden, but only receive 1.34% of health related R&D expenditure (von Philipsborn et al., 2015). R&D expenditure should be raised to match the global disease burden. These changes will not only help PPPs, but it will encourage universities and companies to invest in R&D that decreases poverty.

Third, PPPs need to diversify their funding sources to ensure that they are not overly dependent on a few donors, like the BMGF, for their income. They should target a wide range of foundations, national governments, companies and high net worth individuals. Unless PPPs can find stable sources of funding, then this organizational model will not be a viable tool to encourage more R&D on emerging technologies for poverty alleviation.

Alongside finding new sources of funding, PPPs should encourage donors to develop one reporting standard so that PPPs have more time and money to spend on R&D. This suggestion will face some resistance because it decreases donor control over their contributions. However, if PPPs propose a strong, yet uniform, reporting mechanism, then it is possible that funding organizations will consider a change.

Finally, this study finds that PPPs are concerned that companies will steal their innovations and prevent them from developing technologies, and as a result, PPPs spend a great deal of money and time developing defensive patents. PPPs mentioned that the current patent system limits their ability to develop medicines for DoP. However, reforming IP rights for emerging technologies is very complicated. There are numerous papers on this issue and often scholars give competing advice based on their intellectual traditions (Feachem and Sachs, 2002; Global Forum for Health Research, 2007; Kremer, 2002). Webber and Kremer write that

> *"Patent legislation represents a careful balance . . . Proposals to alter the existing balance should be regarded with caution. Undermining patent protection could discourage innovative activity on the part of industry, while strengthening patent protection could come at the expense of reduced access"* (Webber and Kremer, 2001).

Despite competing policy recommendations, one common suggestion is to loosen the patent laws for low-income countries and for medicines that target DoP (Kremer, 2002). For example, the patent code could allow non-profit organizations, like PPPs and universities, to license IP for a significantly reduced fee if the organization agrees to design and sell that product only to those living below the poverty line. This strategy allows research institutions the access to the necessary IP to develop emerging technologies without going through as many hurdles. In lieu of such reforms, PPPs made special deals with pharmaceutical companies in order to have access to compounds for medicine and vaccine development. Though this strategy has worked, it is highly dependent on the largess of big pharmaceutical companies. Changing the patent system would allow PPPs to be more effective and make it more likely that they will develop other emerging technologies for developing countries.

Science and technologies innovations, like fertilizer or computers, have spawned industrial revolutions and improved the economic conditions of people around the world. It is the hope that emerging technologies, like nanotechnology, will not only lead to new industrial transformations, but also decrease poverty and inequality. Given that many past innovations have actually increased inequality (Woodhouse and Sarewitz, 2007), it necessary to re-conceptualized and create institutions to ensure that poor, marginalized communities also benefit from emerging technologies. PPPs are one category of institutions that can develop emerging technologies to decrease poverty and inequality, but they will not be the silver bullet to guarantee that emerging technology will be inclusive.

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